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Can Technique Modification Training Reduce Knee Moments in a Landing Task?

Alasdair R Dempsey[1,2], Bruce C Elliott[2], Bridget J Munro[3], Julie R Steele[3] and David G Lloyd [2,4]

[1]School of Psychology and Exercise Science, Murdoch University, Perth, WA, Australia

[2]School of Sport Science, Exercise and Health, The University of Western Australia, WA, Perth, Australia

[3]Biomechanics Research Laboratory, University of Wollongong, Wollongong, NSW, Australia

[4]Musculoskeletal Research Program, Griffith Health Institute, Griffith University, Gold Coast, QLD, Australia

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Corresponding Address

Alasdair R Dempsey

School of Psychology and Exercise Science
Murdoch University
90 South Street
Murdoch, WA 6150
Australia
a.dempsey@murdoch.edu.au
+61 8 9360 6526

Abstract

Anterior cruciate ligament (ACL) injuries are costly. Sidestep technique training reduces knee moments that load the ACL. This study examined whether landing technique training alters knee moments. Nineteen team sport athletes completed the study. Motion analysis and ground reaction forces were recorded before and after 6-weeks of technique modification. An inverse dynamic model was used to calculate three-dimensional knee loading. Pre- and post-intervention scores were compared using paired *t*-tests. Maximal knee flexion angle during landing was increased following training. There was no change in valgus or flexion moments, but an increase in peak internal rotation moment. This increase in internal rotation moment may increase the risk of ACL injury. However, the increased angle at which the peak internal rotation moment occurred at follow up may mitigate any increase in injury risk by reducing load transmission.

***Key Words*:** Anterior Cruciate Ligament; Injury; Injury Prevention; Biomechanics

Word Count: 3203

Introduction

Anterior cruciate ligament (ACL) injuries are a serious and common injury occurring in team sports. As most ACL injuries occur in non-contact situations, particularly during sidestep cutting and landing, there is scope for interventions aimed at modifying physical characteristics and/or movement techniques of athletes to reduce injury risk.[1-3] It has been suggested that ACL injury prevention training programs should include balance, plyometric and technique training components.[4] There have been several laboratory-based studies assessing changes induced by plyometric and balance programs on lower limb neuromuscular biomechanics.[5-7] Recent work investigated the effect of technique modification training on sidestep cutting and found knee valgus moments could be reduced with six weeks of training emphasizing correct foot placement and torso positioning.[8] Although a recent study has shown that knee valgus moments can be modified with immediate feedback,[9] no study has comprehensively investigated the effect of a multiple week technique modification program in landing tasks on non-sagittal plane knee joint moments.

Knee joint moments are used as a surrogate measure of ACL load and, in turn, risk of non-contact ACL injury.[10-12] However, most research investigating isolated technique modification in landing with reference to ACL injury, in particular increasing knee flexion, has used ground reaction forces as a measure of knee loading.[13,14] Changes in the ground reaction force do not necessarily reflect changes in knee moments, particularly non-sagittal plane knee moments.[15] Similarly, vertical ground reaction forces do not reflect the magnitude of moments at the knee.[16] Therefore, further research on the impact of isolated technique training on knee moments is required. Studies attempting to modify knee joint angles in landing that have measured loading at the knee have used anterior tibial shear forces and sagittal plane moments.[13,17] However, these parameters do not provide comprehensive information on ACL loading.

The ACL is known to be loaded when the knee experiences anterior tibial drawer, internal rotation moments or valgus moments.[18,19] Additionally, strain on the ACL is increased when these loads are applied simultaneously.[18] Therefore, for this paper it will be assumed that it is a combination of all applied loads that most likely causes ACL injury.

Knee flexion angle alters the transmission of all three knee moments to loading of the ACL. In general terms, as knee flexion angle increases, the resultant load on the ACL decreases.[18] This is exhibited with the greatest transmission of a combination of internal rotation and anterior drawer loads occurring below 10° of knee flexion.[18] However, high ACL loads from a combination of valgus moments and anterior tibial drawer can occur at up to 50° of knee flexion, peaking around 20° to 30° of flexion.[18] Increased ACL loading at more extended knee postures is consistent with results from video analyses of injuries that have shown that at initial foot contact there is a trend for athletes' knees to be in extended postures.[1-3] Lin and colleagues[20] found that in simulations of stop jumps where sufficient ACL loads were produced to cause its rupture, the knee was more extended than when the loads were insufficient to cause ACL rupture. Increasing the knee flexion angle also increases the potential of the biceps femoris to support internal rotation moments, with the internal rotation moment arm increasing approximately fourfold from full extension to 50° of knee flexion.[21] All these findings support the recommendation that athletes should land with increased knee flexion to reduce the risk of non-contact ACL injury,[22] and a number of plyometric based interventions have included cues to increase knee flexion within their drills [23-26]. However, increased knee flexion has yet to be associated with reduced non-sagittal knee moments in either sidestep cutting or landing.[11,12]

Deficits in torso control have also been shown to be related to ACL injuries.[27] During laboratory investigations, increased torso lateral flexion and rotation towards the support leg have been shown to be related to increased valgus and internal rotation moments in sidestep cutting and landing tasks.[12,28] During actual ACL injuries athletes have greater torso lean when compared to athletes performing the same tasks without injury.[29] Technique training to control torso posture in landing may modify knee loading and reduce risk of ACL injury.

Therefore, the aim of this current study was to investigate the effect of a landing technique modification program on knee moments. It was hypothesized that technique modification would result in reduced peak internal rotation and peak valgus knee moments during landing tasks.

Methods

Participants

Twenty-two males currently participating in team sports were recruited to participate in this study (age 20.5±1.8 years, height 180.5±6.6 cm, mass 78.1±14.2 kg). All participants were experienced in performing functional landing tasks through their respective team sport. Participants were excluded if they had a history of major lower limb injury. Five participants withdrew from the study, citing external time constraints, with the remaining participants completing all training sessions. Ethics approval was obtained from The University of Western Australia (UWA) Human Research Ethics Committee and written, informed consent was obtained from all participants prior to data collection.

Experimental Design

The technique modification program was based on the one described in Dempsey et al.[8] for sidestep cutting. It consisted of a six-week program, containing two sessions per week, with weekly training tasks (Appendix 1) based upon weekly goals (Table 1). As the six weeks progressed, training drills moved from closed (controlled) to open (game-like) tasks; a progression shown to produce better skill acquisition outcomes than practice with just open skills.[30] Training was undertaken in small groups of 1-2 participants, with all sessions conducted by the same instructor.

Table 1 Weekly goals on which the landing training program was based.

Week	Aims
1	Start of increased flexion
2	Can do the full task
3	Can perform task catching a ball thrown straight
4	Can perform task catching a ball thrown left or right
5	Can start to do the task with unanticipated ball direction
6	Can perform the task consistently both pre-planned and unanticipated

During each training session, participants were given both immediate (within 1 minute), individualized verbal and visual feedback throughout the session. The visual feedback used TimeWARP (SiliconCOACH, Dunedin, NZ) to provide immediate video feedback on their landing technique together with reference videos of athletes using the desired technique. The visual feedback was either sagittal or from the front depending upon the aspect of the technique being focused on. Verbal feedback was provided alongside the videos and was not structured. Instead, the coach identified deficits in performance and provided cues in conjunction with the video feedback. Both forms of feedback were provided after every trial until subjects could successfully perform the technique while performing the required task. This approach has previously been shown to be successful for sidestep cutting technique modification.[8] Participants aimed to have their torso facing in the direction of travel and not laterally flexed at initial foot contact, while increasing their knee flexion angle throughout the entire landing. This technique was based on the scientific literature.[8,12,22,28,29]

All testing was undertaken at the UWA Sports Biomechanics Laboratory with marker movement recorded using a 12 camera VICON MX motion analysis system sampling at 250 Hz (VICON Peak, Oxford, UK). Ground reaction forces were synchronously recorded at

2000 Hz from a 1.2 m x 1.2 m force plate (Advanced Mechanical Technology Inc., Watertown, USA). Before commencing the trials, participants selected the preferred support leg on which they would both take off and land during the landing task.

We used a landing test that mimicked overhead marking in Australian Football which has been described previously.[28] Briefly the test required participants to take possession of a ball that was falling, under gravity, with the ball starting from the same height that the participant attained in a maximum effort one leg vertical jump. Participants had a five step running approach and took off from the preferred support leg. They were required to land initially on the support leg only, however, there were no restrictions following this. The ball was released by the same trained examiner for each participant and was released to fall either towards or away from the support leg, either early or late in the approach run. We have previously identified that the landing task producing moments most likely to increase the risk of non-contact ACL injury was the ball falling towards the support leg early in the approach run.[28] As such, this task was analyzed for this study. However, participants still performed all four tasks to maintain the challenge of the landing test.

Participants were required to perform three successful trials of each of landing task. The tasks were presented in random order until sufficient trials were performed. A successful trial involved participants taking off and landing on their preferred foot and successfully taking possession of the ball. The landing was required to be on one foot on the force plate.

Data Collection and Analysis

Participants were fitted with retro-reflective markers as per the UWA Full Body Model.[12] Kinematic and inverse dynamic calculations were performed in VICON Workstation (VICON, Oxford, UK) using the UWA Full Body Model, which employs custom code written in MATLAB (Mathworks, Natick, MA, USA) and VICON BodyBuilder (VICON, Oxford, UK). The UWA Full Body Model uses functional methods to identify knee axes and hip joint centers and is described in more detail by Besier et al.[31]. Prior to modeling, both the ground reaction force and position data were filtered using a 4th order 18 Hz zero-lag low-pass Butterworth filter, the filter frequency selected from residual analysis and visual inspection of the data. Inverse dynamics were used to calculate external joint moments,[31] using the body segment parameters reported by de Leva.[32]

The portion of the landing task used to compare knee moments was selected using the vertical ground reaction force data. The landing phase was classified as the period from the point of initial foot contact to double the time from initial foot contact to the time of the peak vertical ground reaction force as has been undertaken previously.[28] Within this phase, the peak knee flexion moment, valgus moment and internal rotation moment were selected for analysis as they have the greatest potential to load the ACL. The moments were normalized to each participant's height (m) multiplied by their mass (kg).[10,12,33,34] Maximal knee flexion angle and knee flexion angles at the time of the peak valgus and internal rotation moment were also identified within this phase. To characterize body posture at landing, the values of the following kinematic variables were determined at initial foot contact: knee flexion/extension, torso flexion/extension, torso lateral flexion and torso rotation. These discrete values where then averaged for each participant.

All moments and joint postures were compared from pre- to post-training using paired t-tests with the alpha set at $p < 0.05$. All statistical procedures were performed using SPSS 17 (SPSS Inc., Chicago, IL). Effect sizes were calculated using G*Power.[35] Where significant changes were identified in the knee moments, Pearson correlations were undertaken to see whether these were associated with kinematic changes identified as significant. Changes were calculated, such that positive values indicated changes that were a priori identified as reducing risk of ACL injury.

Results

There was a significant increase of approximately 10° in peak knee flexion following training but no change at initial foot contact compared to before training (Table 2). Participants initially contacted the ground with a relatively extended knee of less than 10° of knee flexion. Peak knee flexion angle increased approximately 10° following training. There was also a significant increase in the knee flexion angle occurring at the peak internal rotation moment of approximately 15° following training, but not at the peak valgus moment compared to before training.

Table 2 Mean (standard deviation) for knee flexion angle (°) at initial foot contact, peak angle during weight acceptance and peak valgus and peak internal rotation moments.

	Pre	Post	*p*	*d*
Initial Foot Contact	6.8 (7.1)	8.0 (6.2)	0.459	0.20
Maximum*	57.0 (14.5)	66.7 (17.9)	0.010	0.67
Peak Valgus Moment	25.7 (10.5)	30.9 (15.6)	0.250	0.29
Peak Internal Rotation Moment*	31.8 (9.9)	46.2 (21.1)	0.017	0.65

p and *d* are the respective probabilities and effect sizes of the pre- to post-training differences.
* Significant difference at $p < 0.05$

Torso postures did not change after training (Table 3). There were no significant or functional changes for torso flexion/extension, lateral flexion or rotation following training, despite a 17° reduction in torso rotation in the post training testing session compared to the baseline testing session. However, much of this variation is due to large reduction in torso rotation exhibited by three participants (Figure 1 - Participants 2, 5 and 7).

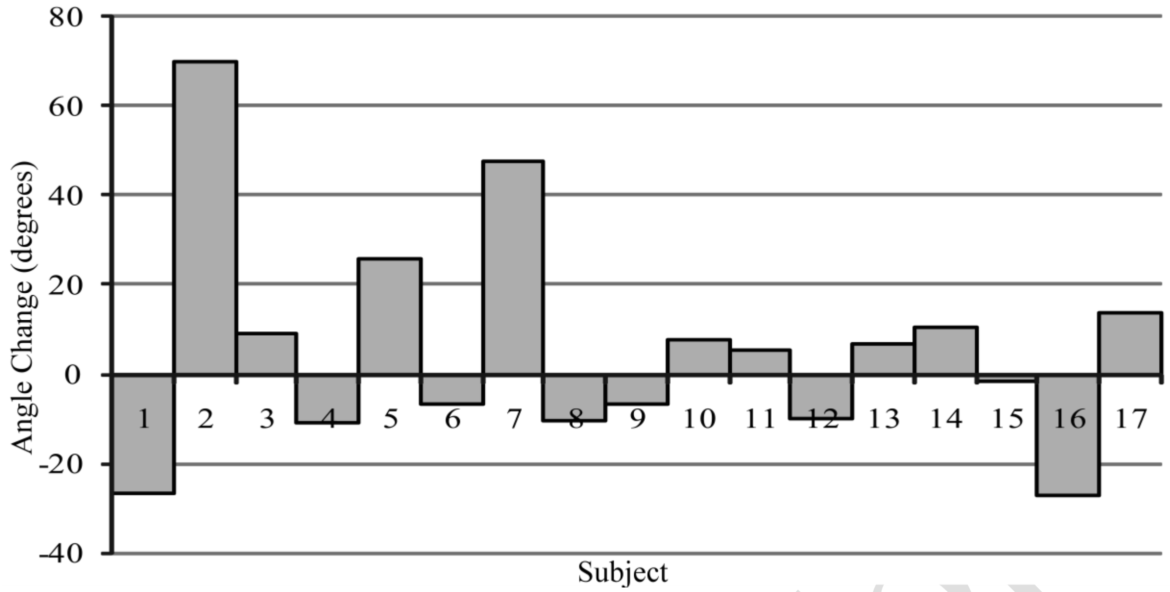

Figure 1 Individual participant changes in torso rotation from pre- to post-training. Positive changes indicate the desired change.

Table 3 Mean (standard deviation) of torso angles (°) at initial foot contact.

	Pre	Post	*p*	*d*
Torso Flexion\Extension	1.3 (10.7)	0.3 (8.9)	0.639	0.12
Torso Lateral Flexion	8.2 (6.3)	5.4 (7.6)	0.263	0.29
Torso Rotation	-43.7 (23.1)	-36.0 (20.4)	0.213	0.32

p and *d* are the respective probabilities and effect sizes of the pre- to post-training differences. A positive value indicates: Torso Flexion\Extension – flexion; Torso Lateral Flexion – leaning right; Torso Rotation – left shoulder back.

Although peak knee internal rotation moment increase following training, there were no changes in either the peak flexion or valgus moment (Table 4). The increase in peak internal rotation moment was correlated with an increase in the maximal knee flexion angle (r = 0.61, p = 0.009), but was not correlated with change in knee flexion angle at the time of peak internal rotation moment (r = 0.07, p = 0.779).

Table 4 Mean (standard deviation) peak knee joint moment data (Nm•kg-1•m-1).

	Pre	Post	*p*	*d*
Flexion	-2.07 (0.56)	-2.03 (0.39)	0.676	0.10
Valgus	0.41 (0.23)	0.32 (0.19)	0.244	0.37
Internal Rotation*	-0.13 (0.05)	-0.20 (0.13)	0.042	0.52

p and *d* are the respective probabilities and effect sizes of the pre- to post-training differences.
* Significant difference at $p < 0.05$.

Discussion

The main aim of this study was to induce technique changes and observe the effect that these changes had on knee joint loading, characterized by knee moments. Specifically, the six-week technique modification program aimed to increase knee flexion during landing and have athletes land with a forward facing, not laterally flexed torso. Although the technique modification program was successful in increasing peak knee flexion, with an average 10° increase in maximal knee flexion angle, there was no change in either the knee flexion angle at initial foot contact or in any of the torso angles.

The unexpected lack of change in knee flexion at initial foot contact may be a result of the methodology used in the training intervention. The current study utilized verbal and visual feedback to train the participants to increase knee flexion. Previous research has shown that verbal feedback can increase knee flexion angles at initial foot contact within a testing session,[36] although these changes are not always maintained.[37] Steele and Munro[37] showed a device that provided concurrent audible feedback to the athlete during landing training was successful in increasing maximal knee flexion and knee flexion at initial foot contact at follow-up testing after using the device for six-weeks. The integration of concurrent feedback into the technique modification program described in this study may result in increases in maximal knee flexion and knee flexion at initial foot contact. The study population may also have limited changes as they were experienced athletes. It may be that applying the same intervention to less experienced athletes may result in further improvements.

Although non-significant and with a small effect size, there was a 17% reduction in torso rotation following training. However, further investigation revealed this reduction to be due to large changes in technique between baseline and follow-up testing displayed by three participants (Figure 1). These three participants demonstrated a large reduction in torso rotation. The lack of change in the remainder of participants, and the lack of change in torso lateral flexion may be as a result of the requirement of the landing task to gather a ball located away from the body on the support leg side. It may also indicate that certain athletes may have more risky techniques, such as torso rotation,[28] and may therefore obtain greater benefit from technique modification training.

While the technique modification program was successful in modifying peak knee flexion, it did not reduce the knee joint moments. There was no change in either the peak flexion or peak valgus moment from pre- to post-technique modification training, although there was a significant increase in the peak internal rotation moment. Despite knee flexion angle not being associated with knee internal rotation moments in sidestep cutting studies [11,12], the relatively strong correlation between the change in maximal knee flexion and change in knee internal rotation moment is indicative of some relationship between the two variables. Therefore, increasing maximal knee flexion angle might be associated with an increased risk of injury, making the current intervention inappropriate for reducing the risk of non-contact ACL injuries.

The increase in the peak internal rotation knee moment needs to be viewed with respect to the effect of the knee angle on the internal rotation moment's transmission to the ACL and potential muscular support. Greatest transmission of internal rotation moments to the ACL occurs in conjunction with the application of anterior drawer below 10° of knee flexion.[18] While the initial contact knee angles were below 10° of knee flexion in the present study, the knee angle at peak internal rotation moment occurred well outside this range at both pre- and post-intervention. The observed 15° increase in knee flexion angle also increases the potential for the biceps femoris to support the internal rotation moment, with an approximate doubling of the external rotation moment arm of both heads of biceps femoris.[21]

As we did not assess muscle activation during the landing in this study we cannot identify actual increases in muscular support. However, peak internal rotation moments occurring further from the joint angle where greatest transmission occurs, coupled with a potential increase in muscular support, might be protective of the joint despite the increase in the magnitude of the moment.

The increase in maximal knee flexion angle did not affect the knee angle occurring at the peak valgus moment. When applied in conjunction with anterior drawer loads, peak transmission of valgus loading to the ACL load occurs in the range 20° to 40° of knee flexion.[18] In the current study, the peak valgus moment occurred at knee angles within this range. While increased knee flexion angles increase the potential for muscular support for internal rotation moments, the opposite is true for valgus moments.[38] As increasing knee flexion angles did not affect the angle at which the peak valgus moment was applied, and increased knee flexion decreases the potential for support,[38] the value of increasing knee flexion angle to reduce the risk of injury from valgus loading is questionable.

The results from this study do not directly support the recommendation to increase knee flexion to reduce ACL injury risk. However, from the literature it is clear that the relationship between knee angle, knee moments and ACL load is complicated. Work needs to be undertaken utilizing neuromuscular skeletal modeling tools, coupled with actual electromyography from the knee musculature with results used to drive models of ACL load under a variety of conditions. This will allow us to identify the ideal landing technique to prevent ACL injury and the development of training programs to enable athletes to develop this technique. When developing these techniques, however, the requirements to prevent non-contact ACL injuries should not be considered in isolation as induced changes may increase the risk of other injuries. For instance, increased knee flexion during jumping tasks has been related to patellar tendinopathy.[39,40]

Results and conclusions from this study should be viewed in context of the limitations of this study. The task selected in this study is reflective of an overhead mark in Australian football, a task during which ACL injures are known to occur.[1] ACL injures also occur during vastly different landing tasks such as shooting for a goal in European handball.[3] The resultant technique and loading may be different between different movements, and therefore the impact of increasing knee flexion may also differ between landing tasks. Investigations should also be undertaken into both the kinematic and kinetic profiles of varied landing tasks, and the impact of technique modification within each of these. The current study also only investigated one participant group and did not compare to controls. This should be undertaken in order to ensure that changes reported are not solely due to time effects and are the result of the technique modification program.

Despite these limitations this paper has demonstrated that it is possible to modify landing technique in experienced athletes. Further work is needed to identify the ideal landing technique for reducing the risk of non-contact ACL injury and to identify whether it can be successfully implemented in the field environment.

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